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UAVS AND ISR SENSOR TECHNOLOGY

by

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Preface

As a young officer, a quote from Lt. General Robert F. Raggio, a former F-22 Systems Program Director, greatly influenced my perception of the military. General Raggio observed that "We are transforming from a military of effectiveness to a military of efficiency." This statement was a reference to the post Cold War absence of a peer competitor and the subsequent shrinking defense budgets as part of the 'peace dividend.' However, the emerging global engagement policy of the US has added another wrinkle in that the military is now operating at a higher tempo than during the Cold War. The combination of reduced budgets with increased taskings requires the military to be extraordinarily innovative and efficient. Fortunately, the combination of maturing unmanned flight vehicles with advanced sensors and information technologies genuinely offers the opportunity for the Air Force to improve its intelligence, surveillance, and reconnaissance capabilities while lowering cost and minimizing the threat to human life.

I extend sincere appreciation for everyone who assisted in the preparation of this paper. I am thankful for the thought-provoking and insightful comments of Lt Col Steve Kimbrell, my faculty advisor, whose involvement significantly improved the quality of this work. I also appreciate the candid interviews of colleagues from the Air Force Research Laboratory and DARPA. I am also pleased to recognize the outstanding support provided by the members of Gateway Baptist Church who provided spiritual encouragement every step of the way. Finally, I give my highest thanks to God who gave me my wife, Dawn, and my two daughters, Sarah and Grace.

Abstract

This paper examines the Air Force's need to aggressively pursue development of unmanned aerial vehicles (UAVs) and sensors for airborne intelligence, surveillance, and reconnaissance (ISR) data collection. Additionally, recommendations for optimizing the employment and development of ISR UAVs and sensors are addressed. The transformation of the US military from a Cold War conventional force towards a global expeditionary force has created a growing demand for air power including deployable, long endurance ISR assets. UAVs equipped with advanced sensors were superb ISR performers in the 1990's and possess the potential to provide a long-term, air power alternative for enhancing the nation's ISR capability. The Air Force must embrace emerging sensor and information technologies to maintain the pace of innovation. Technological advances are redefining old paradigms on how to best conduct the ISR mission. In the near term, the Air Force should continue efforts to integrate UAVs with other manned and spaceborne ISR assets. The horizontal integration of these assets into a tightly coupled system of systems will provide a great leap forward. For the long-term, the Air Force must address its shortfalls in R&D funding. A healthy technology base is required for revolutionary technologies such as micro-electro-mechanical systems (MEMS), micro air vehicles, and hyper-spectral imaging. Finally, the Air Force should establish a unifying vision for ISR UAVs to focus development while also providing a platform to advocate the unique merits of air power in the form of airborne ISR.

Chapter 1

Introduction

While ISR platforms have evolved, the mission remains the same—provide the fullest possible understanding of the adversary to the commander.

—AFDD 2-5.2[1]

Unmanned (or uninhabited) aerial vehicles (UAVs) are methodically becoming a central theme in the mosaic of Air Force systems and capability. The questions regarding employment of UAVs are not so much about if they should be developed but how to integrate them into Air Force doctrine and organizations. The AF 2025 Study identified reconnaissance UAVs as one of the high leverage systems of the future. Accordingly, the Air Force has made a concerted effort to develop UAVs and sensor technologies with a particular emphasis on intelligence, surveillance, and reconnaissance (ISR) applications.[2] This paper addresses considerations for improving the future application of UAVs for the ISR mission. Specifically, this research illustrates that UAVs in concert with manned and space assets addresses several Air Force ISR needs. Furthermore, the Air Force should seize the opportunity to leverage the rapid advances in sensor and information technology to increase the capability of UAVs to perform ISR while also performing other vital air power missions.

Statement of Research Question

The questions addressed by this research are: (1) should the USAF proceed with aggressive development of UAVs for ISR, and (2) what are key considerations to improving the return on investment in UAV and ISR sensor technology.

Significance of the Research

UAVs have been proposed for several mission areas including ISR, communications, and weapons delivery. The Predator UAV was used extensively in Kosovo, and other UAV platforms such as Global Hawk are now in flight test. Direction is needed to ensure these maturing UAVs are used in the most effective way. Also, applying appropriate acquisition priorities are essential to nurturing the UAV and sensor technology base to optimize mission performance. This research is critical as there is an on-going revolution in sensor technology that will improve the UAV's ability to perform ISR missions now conducted by high-value, manned assets. However, there is a limited amount of military research and development funding available to take advantage of this unique opportunity. Consequently, DoD must make wise choices in deciding how to invest its limited development funds to reap the highest performance dividends now and in the future.

Paper Organization

Chapter 2 addresses the growing importance of UAVs and sensors to meeting Air Force ISR needs. An assessment of USAF requirements points toward deficiencies in ISR capability as a constant across virtually all employment scenarios. This chapter proves UAVs provide an effective and cost-efficient solution particularly when used in combination with manned ISR platforms. Chapter 3 addresses the importance of ISR sensors and prime mission equipment. Current UAV programs have rightly emphasized the development of airframes, but the military utility of UAVs is also dependent on revolutionary sensors and avionics. Chapter 4 recommends future directions emphasizing a desire to merge ISR and other missions onto a single UAV platform, as well as the need for a long-term vision for ISR UAVs and sensors. Chapter 5 concludes the paper by recapping the ability of UAVs to perform ISR as well as a proposal to place higher priority on invigorating development of UAV sensors and mission technology.

Notes

[1] Air Force Doctrine Document 2-5.2, "Intelligence, Surveillance, and Reconnaissance Operations," 21 April 1999, ii.

[2] Lt Gen Jay W. Kelley, *2025 Executive Summary* (Maxwell AFB, AL.: Air University Press, 1996), 36.

Chapter 2

Importance of UAVs and ISR Sensors

You can never have too much reconnaissance.

—Gen. George Patton[1]

The Increasing Demand for ISR

The post Cold War strategy of engagement has placed a premium on ISR and increased use of UAVs in the future. The 1997 National Military Strategy (NMS) requires a robust all-source intelligence capability to enable the worldwide application of US military power.[2] The NMS states, "A globally vigilant intelligence system that is able to operate in a complex environment with an increasing number of potential opponents and more sophisticated technology is critical."[3] Furthermore, the future strategic environment requires continuing innovation. For example, Joint Vision 2020 identifies global engagement, spread of technology, and improved adversary tactics as having significant implications for US military forces.[4] Consequently, the US must evolve its ISR capability through innovations such as UAVs to contend with the dynamic strategic environment.

The Air Force has also recognized the importance of increased global ISR as a necessary parallel to support the strategy of global engagement. An Air Force Scientific

Advisory Board (SAB) study documented that the ISR requirements for a global expeditionary Air Force differ significantly from the conventional war paradigm which spawned the current set of Air Force ISR assets.[5] Moreover, the SAB study stressed that global engagement requires ISR which is: (1) timely and responsive, (2) available anywhere in the world, (3) has the versatility to monitor wide expanses of land or the movements of small groups of people, (4) and can operate in an ambiguous legal and political environment.[6] Hence, similar to the renaissance in the Air Force for the appreciation of strategic attack, the new expeditionary nature of Air Force operations has also reinvigorated discussion on the merits of persistent, worldwide ISR collection.

The call for increased and improved ISR capability was clearly illustrated in the "Future Modernization Priorities and Processes" briefing presented at the 1999 Corona Conference. In this presentation, the Air Force's top military acquisition and plans officers presented several options for transforming the Air Force to best meet growing expeditionary requirements.[7] The options included maintaining the status quo, pursuing increased funding, adopting a long-range, standoff posture, and recapitalizing the force structure. In addition, the general categories of forces considered were fighters, long-range strike, munitions, airlift/tankers, and ISR/battle management.[8]

The importance of ISR was underscored in that it was the only category recommended for significantly increased funding in every scenario. This is an astounding insight as Air Force leaders considered trading fighters, bombers, and/or airlift to procure increased ISR capability! Moreover, the briefing specifically advocated the increased use of UAVs for ISR.[9]

The results of the Corona modernization briefing corroborate the recommendations of other Air Force leaders with respect to the employment of UAVs for ISR. As stated in Chapter 1, the AF 2025 Study identified UAVs as a high leverage technology for the future.[10] The Air Force Posture Statement 2000 also endorses UAVs by stating, "The Air Force will continue to exploit the technological promise of UAVs and explore their potential uses over the full range of combat missions."[11] Finally, the current Air Combat Command Commander points to ISR UAVs as an essential element of the Global Strike Task Force concept designed to maximize the effectiveness of the future Air Force.[12] The Air Force has recognized the growing value of ISR for expeditionary operations and concluded that the marriage of UAVs and advanced sensors provides improved air power capability for the future.

Growing Interest in UAVs

UAVs have garnered increasing notoriety in the past decade due to their usefulness as platforms for ISR information. ISR collection is a critical factor in achieving the Joint Vision 2020 operational concept of precision engagement which is "the ability of joint forces to locate, surveil, discern, and track objectives or targets."[13] The US has evaluated and employed UAVs or remotely piloted vehicles (RPVs) since World War I with varying levels of success.[14,15] However, the current resurgence in UAV interest is primarily driven by their outstanding performance in the 1990s in Operations DESERT STORM, DELIBERATE FORCE, and ALLIED FORCE.

UAVs were successfully employed in the Gulf War to provide enhanced ISR capability. The primary Gulf War UAV was the Pioneer (Figure 1) which was used due to a shortage of manned ISR assets.[16] Despite its shortcomings, the Pioneer supported every service and was used for “direct and indirect gunfire support, day and night surveillance, target acquisition, route and area reconnaissance, and battle damage assessment (BDA).”[17] Furthermore, the DoD Final Report on DESERT STORM stated that “UAVs proved excellent at providing an immediately responsive intelligence collection capability.”[18] Thus, DESERT STORM provided an opportunity for UAVs to demonstrate their prowess at BDA and ISR which was affirmed again in the Balkans.

Figure 1. Pioneer UAV (Pioneer UAV, Inc. Photo).

US operations in the Balkans have substantiated the ability of UAVs to provide timely ISR to military commanders. As the workhorse UAV, the Predator has logged over 20,000 hours and made several combat deployments to the Balkans.[19] The Predator, in concert with other UAVs and ISR collection platforms, provided invaluable real-time intelligence. A recent article stated:

> [a] technological star of the war was the UAV, the unmanned aerial vehicle, which in Kosovo was used only for reconnaissance but can almost certainly be used for more violent purposes. The fact that the UAVs could loiter over dangerous areas without risk to human life or at unbearable economic cost (they are only $3m apiece) was of huge value.[20]

Ultimately, UAVs even made a convert of Lt. Gen. Michael Short, Commander of Allied Air Forces during the Kosovo campaign: "I went into this war with a lukewarm approach to UAVs…and I came out of this conflict as an enormous fan of the unmanned aerial vehicle."[21] Clearly, UAVs have proven themselves as valuable ISR tools in the 1990s and are recognized by DoD and Air Force leaderships as a key building block for air power in the 21st century.

Why Use UAVs for ISR?

The decision to pursue UAVs to meet the growing demand for ISR is based on political considerations, increased effectiveness, and reduced cost. The mounting requirement to avoid casualties in military operations is a compelling reason for using UAVs. Clausewitz warned that war and politics were inextricably linked, and his dictum is particularly relevant in today's casualty-adverse political-military environment. From Maj Gary Powers to Capt Scott O'Grady, the loss of a single airman can change the context of global politics. Conversely, the loss of a pilotless UAV does not appear to hold the same level of consequence. For example, the downing of Capt Scott O'Grady held the nation captive until his recovery.[22] However, the loss of over a dozen UAVs in the skies over Kosovo elicited no discernible political reaction.[23]

The ISR mission is particularly germane to casualty avoidance as manned ISR platforms such as AWACs and JSTARS are large aircraft with limited maneuverability and self-defense. ISR aircraft also fly long missions with predictable flight patterns to allow their sensors to build a picture of the battlespace. Moreover, these aircraft carry large crews which would greatly magnify the social and political ramifications of their loss. The political fallout from the loss of a JSTARS in Kosovo would greatly exceed the consternation that occurred over the loss of a single-seat F-117. Conversely, the loss of several Predators over Kosovo did not bring severe political repercussions and illustrates the desirability of UAVs for dangerous ISR missions.

Beyond political benefits, UAVs can increase the effectiveness of ISR collection by augmenting manned and spaceborne platforms. The worldwide demand for ISR greatly exceeds the capacity of manned platforms.[24] UAVs can supplement low-density, high-demand assets such as AWACS and JSTARS by providing additional sensor coverage and reducing the stress on manned platforms. Additionally, UAVs possess the capability to provide long-dwell surveillance by loitering over targets of interest for extended periods of time. Moreover, high-flying UAVs can act as 'a poor man's satellite' by providing a high altitude (40-60K'), look-down perch for sensors to scan targets of interest.[25] UAVs have the advantage over satellites in that they are more easily retasked, reconfigured, and upgraded to take advantage of different payloads or new sensor technology.[26] Finally, satellite orbits are predictable--allowing adversaries to anticipate satellite surveillance, whereas UAVs have greater ability to alter their flight paths and coverage. Thus, UAVs are an important insurance policy as US satellites are becoming a high priority target for adversary nations.[27]

Another attractive feature of UAVs is lower cost relative to other types of ISR assets. The high cost of manufacturing, launching, and maintaining satellites makes UAVs an attractive option for ISR. High altitude, long-endurance UAVs can provide many of the same capabilities as satellites but at reduced cost. Similarly, UAVs possess a cost advantage over manned aircraft in performing sensing missions. A study comparing the costs of UAVs and manned ISR platforms concluded:

> Several previous studies, including the 1997–1998 Office of the Secretary of Defense (OSD) Airborne Radar Study (ARS), the Assistant Secretary of Defense (C^3I) command, control, communications, computers, intelligence, surveillance, and reconnaissance (C^4ISR) Mission Assessment Study, and six recent SAB studies, examined the acquisition, operating, and life-cycle costs of manned ISR platforms and UAVs. Each

> of these studies showed convincingly that UAVs are significantly less expensive than manned counterparts.[28]

As the demand for ISR grows in the future, the benefit of averting human casualties, enhancing ISR mission effectiveness, and lower operating costs of UAVs clearly mark them as desirable complements to space and manned assets. As stated by Lt Gen Short:

> UAVs offer us so many things. Not only do they provide long-dwell capability, but at not near the cost of a manned platform, and clearly they do not incur the risks to our people that a manned platform does. I think there is enormous potential in UAVs, and I think this nation needs to explore that.[29]

Two UAVs that the Air Force is using to explore and exploit the potential for UAVs are the RQ-1 Predator and the RQ-4 Global Hawk.

Predator and Global Hawk

The RQ-1 Predator is a medium altitude endurance (MAE) UAV used for real and near real time imagery reconnaissance. The Predator program started in 1995 as an advanced concept technology demonstration (ACTD) to develop an all weather day/night capability to perform long dwell surveillance over target areas. The Predator was deployed to the Balkans less than 19 months after the program started and performed superbly by providing a constant vigil on Serb forces.[30] Predators were also used extensively in Kosovo in 1999 and are now assigned to operational flying squadrons in the Air Force. The Predator has electro-optic (EO), infrared (IR), and radar sensors that allow day/night operation in all weather. The Predator can transmit imagery through its line-of-sight radio or over the horizon using a satellite link. Finally, a recent field test demonstrated the ability of the Predator to successfully carry, target, and launch an air to surface missile.[31] Figure 2 shows a Predator and Table 1 list key system specifications.

Figure 2. Predator UAV (General Atomics Photo).

Table 1. Comparison of Predator and Global Hawk.[32]

Characteristic	*RQ-1 Predator*	*RQ-4 Global Hawk*
Wing Span	49 ft	116 ft
Length	27 ft	45 ft
Speed	50-120 knots	300-400 knots
Max Altitude	25K ft	65K ft
Operating range	400 nm	3000 nm
Endurance	40 hrs	40 hrs
Sensors	EO/IR/SAR	EO/IR/SAR
Cost	~ $3M	~ $10-15M

The RQ-4 Global Hawk (Figure 3) is the high altitude long endurance (HAE) UAV companion to Predator. The Global Hawk was designed for long range deployment and wide-area surveillance or long sensor dwell.[33] Like Predator, Global Hawk carries an array of EO/IR and radar sensors to perform all weather, day/night surveillance. The Global Hawk also started as an ACTD to accelerate its development. After a slow start, the program has experienced significant success, and the Air Force is now committed to acquiring systems for operational use. The Global Hawk has a range of over 3,000 nm, an endurance of nearly 40 hours, and operates at altitudes up to 65,000 feet as shown in Table 1.

Figure 3. Global Hawk UAV (Teledyne Ryan Photo).

The transformation of the Air Force towards an expeditionary fighting force with worldwide responsibilities has created an enormous demand for ISR. As a result, military planners have turned to UAVs to provide a cost-effective means of providing air power through increased ISR capability. William Cohen, the Secretary of Defense summarized the situation when he wrote:

> We are at a critical juncture in airborne reconnaissance. Forty years ago we were at a similar crossroads and committed to the development of our nation's successful high-altitude manned aircraft. Technology…has moved forward at an amazing pace, and the demand for information has increased even more quickly. The opportunity is here to develop, acquire and integrate unmanned airborne reconnaissance capabilities into the force structure at a rapid, but prudent rate.[34]

Hence, it is clear that the Air Force should continue to aggressively pursue UAVs for ISR applications, and Chapter 3 addresses the issue of developing sensor technology to get maximum return on the investment in UAVs.

Notes

[1] Brendan P. Rivers, "The Future of ISR," *Journal of Electronic Defense*, December 1999: 37-41.

[2] Gen John Shalikashvili, *National Military Strategy of the United States of America* (Washington DC: US Government Printing Office 1997), 28.

[3] Ibid.

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[4] Gen Henry H. Shelton, *Joint Vision 2020*, (Washington DC: US Government Printing Office, 2000), 4.

[5] Tom McMahan and Dr. Peter R. Worch, *USAF Scientific Advisory Board Report on Technology Options to Leverage Aerospace Power in Operations Other Conventional War, Volume 1: Summary SAB-TR-99-01*, (February 2000), 18.

[6] Ibid.

[7] Lt Gen Martin and Lt Gen DeKok, Future Modernization Priorities & Processes, unpublished briefing, October 1999.

[8] Ibid.

[9] Ibid.

[10] Lt Gen Jay W. Kelley, *2025 Executive Summary* (Maxwell AFB, AL.: Air University Press, 1996), 36.

[11] F. Whitten Peters and Gen Michael E. Ryan, "Air Force Posture Statement 2000," on-line, Internet, available from http:// www.af.mil/lib/afissues/2000/posture.

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[13] Gen Henry H. Shelton, *Joint Vision 2020*, 22.

[14] Lt Col Richard M. Clark, *Uninhabited Combat Aerial Vehicles*, (Maxwell AFB, AL.: Air University Press, 2000), 6-34.

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[21] Linda De France, "UAVs Hold Key To Future Conflicts, Kosovo Air Commander Says," *Aerospace Daily*, 15 November 2000.

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[33] Michael F. Miller and Richard A. Best, Jr., *Intelligence Collection Platforms: Satellites, Manned Aircraft, and UAVs* (Washington DC: Congressional Research Service, 1998), 18.

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Chapter 3

UAV Sensor and Information Technology

Victory smiles upon those who anticipate the changes in the character of war not upon those who wait to adapt themselves after the changes occur.

—Giulio Douhet

The development of ISR UAVs has reached a point where an increased focus on sensor payloads and technology is critical to fulfill the national military strategy of "preparing now for an uncertain future."[1] Predator and Global Hawk will provide immediate near-term benefit because they fill a current void in US intelligence gathering capability. However, the move to an expeditionary air force along with changes in the character of war and global politics dictate an aggressive and forward-looking posture in the development of sensors to secure the long-term usefulness of UAVs.

Advanced Sensors and Technology

The anticipated changes in the nature of war will produce not only an increased demand for ISR but also require new ISR capabilities that do not currently exist. As the Air Force moves into the 21st century, factors such as asymmetric warfare, the evolving role of the Air Force, and technology proliferation create a requirement for enhanced UAV sensors.[2] The growth of asymmetric warfare will necessitate increased ISR as adversaries attempt to counter the overwhelming superiority of conventional US forces with unconventional operations. Future adversaries are expected to resort to terrorism, weapons of mass destruction, and information operations to attack the US. The development of airborne sensors, which can track targets in all types of terrain throughout the spectrum of military operations, will allow the US to defeat asymmetric and conventional threats.

Moreover, the Air Force's increasing involvement in global operations will require engaging threats with little or no support from traditional sources of intelligence. As Operation Allied Force demonstrated, air power was the primary force used to engage an enemy. The lack of ground forces engaged with the enemy eliminates a vital source of intelligence gleaned from surface recon patrols.[3] The absence of a ground offensive allows the enemy to camouflage or conceal their assets to prevent airborne detection. As stated in a recent article, "The inability to track targets in the jungle, a technological shortfall smoothed over by a series of operations in the desert, reappeared in Kosovo where the Yugoslav army stopped moving, dug in, covered up and virtually disappeared to US surveillance."[4] Hence, the effective application of air power in the future will require an increased ability to project precision munitions and also provide precision, airborne ISR capable of long dwell surveillance and finding targets in a variety of environments. UAVs equipped with advanced sensors will provide formidable air power force enhancement by finding moving and concealed targets.

The Air Force should pursue two avenues for developing UAV sensor technology. The first approach is a near-term focus on combining existing UAV technologies into an integrated system of systems to provide a common operational picture. Second, the Air

Force should pursue long-term technology development to design new ISR UAV sensors.

Near Term Technology

One near-term method of improving ISR is to integrate UAV, manned, and satellite sensor data to create a common operational picture. A key to solving the problem of engaging pop-up targets "requires a near real-time, staring and dwelling, constantly refreshed picture of the ground."[5] Placing ISR sensors on UAVs provides long dwell surveillance to cue other players in the time critical targeting process. The linking of UAV sensor data with other systems creates a dynamic picture of the battlespace, which then allows commanders to engage targets more quickly. UAVs such as Predator and Global Hawk possess UHF/VHF, C-Band, and satellite links that enable sensor data transmission to warfighters in the field or to decision-makers worldwide.

Furthermore, intelligent use of information technology can improve the effectiveness of existing UAV sensor technologies in the near-term. Development of appropriate processes and tactics will improve the interaction between UAVs and other forces. For example, an exercise at the national training center successfully combined a camera-equipped UAV with a JSTARS aircraft to surveil enemy movements.[6] As stated by the company commander, "The UAV maintained a broad focus throughout the mission; however, the impact of the live feed coupled with the JSTARS moving target indicator display was obvious, allowing a real-time intelligence picture for the battlestaff."[7] In addition, the concept of using information technology to fuse data from ISR UAVs and other platforms was validated during the Joint Expeditionary Force Experiment (JEFX)

2000.[8] The experiment results were extremely positive and support the benefit of using information technology to enhance ISR UAV sensor performance.

Another near-term approach to improving ISR is to use multiple sensors to detect and track targets through sensor fusion. Datalinked UAVs can share their data to allow passive detection and identification of targets.[9] For example, the UAV Battlelab conducted an experiment using UAVs equipped with direction finding equipment[10]. The UAVs were able to passively track and geo-locate emitters by comparing when radar pulses struck the antennas of the datalinked UAVs.[11] Moreover, the combination of long endurance UAVs with passive ISR techniques allows UAVs to operate without revealing their presence.

In addition to using positional data, combining sensors using different aspects of the electromagnetic spectrum produces a hybrid, multi-spectral system. Multi-spectral systems use sensors operating at different frequencies to evaluate a target. Each frequency band reveals different target characteristics, and evaluating the results from all of the sensors can allow target detection where an individual sensor would have failed.[12] For example, linking UAVs with VHF and UHF radars forms a hybrid multi-spectral system. The VHF UAV can better detect targets under trees because the lower VHF frequencies have greater foliage penetration; however, the higher frequency UHF radar can provide better target classification because UHF images have higher resolution.[13] Combining these two UAV-borne sensors into a multi-spectral system allows superior target detection and imaging over each sensor operating independently.

Many other complementary sensor combinations, such as electro-optical (EO) and radar, exist which combined with UAVs provide a potent, multi-spectral ISR asset. In summary, all of these near-term sensor technology thrusts offer great potential toward improving ISR UAV capabilities as evidenced by the DoD's top acquisition official:

> I fully expect that we're going to be doing a lot more with remotely piloted vehicles. But if you put all the systems into a single large platform, it makes it a more vulnerable target. Why not put multiple sensors on multiple platforms? Looking at a target from several UAVs lets analysts look at targets from several angles and can provide better identification. … I think you're going to have multiple spectrum systems over the battlefield for reconnaissance within five years.[14]

Long-Term Technology

Revolutionary new sensor technology will further enhance the long-term viability of ISR UAVs. Numerous advances in sensor technology are on the horizon including innovations in computing, hyperspectral imaging (HSI), micro-electro-mechanical systems (MEMS), and new antennas. These advances will provide affordable UAV sensors with far greater capability than the current state-of-the-art.

Microprocessors are exponentially improving in speed, size, and cost which will provide UAVs of all sizes with revolutionary computing ability. Analysts predict Moore's Law will be valid for the next 15 to 20 years which indicates that the number of transistors on a chip will double every 18 months.[15] Increased transistor density along with advanced electronic packaging should produce a 10x improvement in computing power every 4-6 years. Moreover, microprocessors are batch fabricated which means that hundreds to thousands of devices are produced in parallel. Batch fabrication combined with advances in material science and the incredible efficiency of the competitive microelectronics industry will result in significantly lower cost for each new generation of computer technology.[16]

The Joint Strike Fighter (JSF) processor is an example of improvements in computing technology. Compared to the F-22 developed in the early 1990's, the JSF processor has significant advantages in size, speed, and cost. A member of the JSF program stated:

> …the JSF processor is an order of magnitude more capable [than the F-22], which you'd expect, but at a fraction of the cost. Another critical decision was to adopt a software architecture which ensures that as microprocessor technology improves--with a new generation emerging about every 18 months--developers can take the same software and just reuse it with new hardware.[17]

This example illustrates the amazing and affordable computing power that will be available for UAVs to improve their ability to perform complex ISR sensor processing.

Another revolutionary technology for ISR UAVs is hyperspectral imaging (HSI) or imaging spectroscopy. While a multi-spectral system examines a limited number of frequency bands, a hyper-spectral system examines hundreds of frequency slices in the electromagnetic spectrum for patterns or anomalies.[18] Most materials have unique spectral features, and HSI measures the absorption pattern to find target characteristics not visible by other sensors. This approach allows identification of a variety of targets, including weapons of mass destruction.[19]

HSI sensors are well suited for high altitude, long endurance UAVs. UAVs can loiter at high altitudes allowing the hyperspectral sensor to look down over the target at various angles. This combination may even provide a limited ability to detect camouflaged or hidden targets if the HSI sensor is able to peek through foliage or concealment to see the target.[20] In addition, the UAV can carry traditional radar and EO/IR sensors to cue the HSI system to look at specific targets. The DoD's top acquisition official is optimistic about the combination of UAVs and hyperspectral imaging and expects this technology to be available in ten years.[21]

MEMS technology will also have a long-term impact on UAVs and sensor technology. MEMS processes create mechanical devices with micron (10^{-6} meters) feature sizes by using many of the techniques used in the semiconductor industry.[22] MEMS devices are already prevalent in the automotive industry (air bag deployment and pressure sensors), ink printers (nozzles), and optical projectors.[23] Researchers are investigating MEMS devices to replace costly components in many radio frequency (RF) and optical sensor systems since they can be cheaply fabricated using batch processing.[24,25] In addition, many MEMS devices are controlled using electrostatic actuation which allows ultra low-power operation, an important consideration for UAVs with limited power. For example, a passive MEMS RF phase shifter was built that exceeded the performance of other semiconductor devices, used one-tenth the power, and was 80% cheaper than any competing technology.[26]

MEMS sensors and components are considered essential to creating a new class of UAVs called micro air vehicles (MAVs). DARPA is sponsoring several demonstration programs (Figure 4) to develop MEMS and other technologies essential to making small UAVs.[27] MAVs as small as a large insect (~6 inches in any dimension) are envisioned for ISR missions in urban environments or close-in tactical situations.[28] British scientists are also working on MAVs for ISR as stated in a recent article:

> The inspiration to build the tiny plane, which will weigh 100g (3.5oz) and carry tiny cameras weighing about ten grams, arose from Britain's peace-keeping efforts in Sarajevo. In 'Snipers' Alley' in the Bosnian capital, Serbs hiding in deserted flats turned the area into a killing field because they could pick off their victims with ease. Spy satellites and reconnaissance planes proved useless because they could not peer inside

> the buildings. Bombing the area was unacceptable because of the risk to nearby civilians.[29]

Clearly, MEMS technology combined with micro UAVs and advanced sensors are of great long-term value to the Air Force.

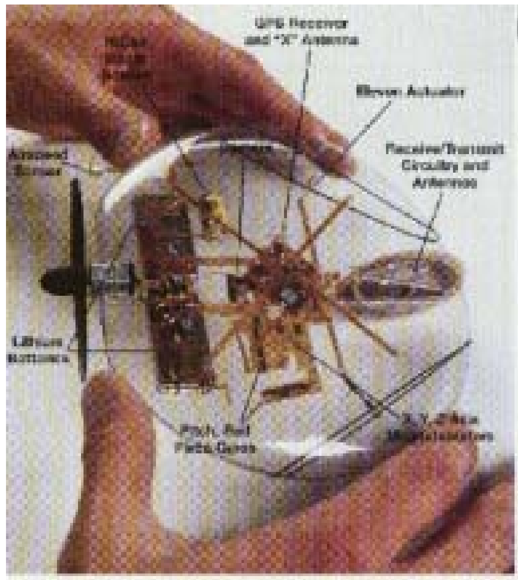

Figure 4. Micro air vehicle prototype (AeroVironment/Caltech Photo).[30]

Finally, advances in antenna technology will greatly improve the ISR capability of UAVs in the future. The development of compact and low-cost active electronically scanned antenna (AESA) arrays holds great promise. AESAs combine the output from hundreds or thousands of small, individual transmit-receive (T/R) modules to create a composite antenna pattern. An AESA radiation pattern is electronically scanned by controlling the output of each T/R module. An AESA can move its antenna beam much more rapidly than a mechanically scanned antenna and has higher reliability due to the reduction in moving parts. Moreover, AESAs programmed to create a wide variety of waveforms can simultaneously support multiple functions.[31] For example, a properly configured AESA can perform both air-to-air and air-to-ground ISR.[32] AESA technology is ideal for UAVs because of the high reliability, absence of mechanical gimbals, and flexible waveform generation.

Furthermore, recent advances in the design and fabrication of T/R modules will make AESAs more affordable for UAVs. A recent article states, "Since 1994, the depth of T/R modules has decreased by 90%, weight has dropped 83% and cost has fallen by 82%. The key has been architectural changes in the T/R module along with automated assembly and testing, which reduces labor time."[33] Moreover, the cost of X-band T/R modules was nearly $10,000 in the early 1990's but has dropped to around $500 in 2000.[34] Further cost reductions are expected from the use of new materials and MEMS. The low cost, weight, and form factor of new T/R modules will enable use of AESAs on ISR UAVs from the small MAVs to the large Global Hawk.

Case Study: Importance of Understanding Future Technology

Understanding the nature and quality of emerging near and far-term sensor technologies is absolutely critical to making wise decisions regarding ISR UAV programs. An informed choice regarding the progress of technology will mitigate a common malady identified by Air Armament Center Commander Gen Kostelnik:

> One of the biggest flaws in our thinking is that we are thinking about tackling a problem ten years from now with the capability that we have today. We have to quit thinking about ourselves in the way we are today and the way we have been in our past. We have to look back at our past, see how much things have changed, and project a different future.[35]

The Air Force's decision to restructure the Radar Technology Insertion Program (RTIP) demonstrates the forward thinking encouraged by Gen Kostelnik. The RTIP program was initially planned as a radar upgrade for a select number of JSTARS aircraft, but the Air Force backed away due to high costs and the limited scope of the program.[36]

A Defense Science Board study turned to government and industry experts and realized that the rapid progress of AESA and other technologies allowed the development of a modular radar suitable for use on a wide variety of platforms including UAVs.[37] This decision was made possible by an educated appreciation of the advances in sensor technology combined with maturing of UAV airframes.[38] Now, the Air Force is developing a high-payoff program that will provide substantially improved ISR UAV capability as opposed to the more limited program initially proposed.

The RTIP case study illustrates the importance of understanding the current and future state-of-the-art for optimal development of UAVs. Making the right choices on UAV and sensor technology is critical for the Air Force to get the maximum benefit from its limited budgets; and Chapter 4 recommends actions the Air Force should pursue for optimum development of UAVs and sensors for ISR applications.

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Chapter 4

Recommendations for the Future

Where there is no vision, the people perish.

—Proverbs 29:18

There are significant issues facing the successful development and fielding of ISR UAVs, and the Air Force needs a far-reaching vision which supports the employment of UAVs as part of an affordable, integrated network of air, land, and space ISR assets. Chapters 1-3 developed a case advocating the use of UAVs and advanced sensor technology to support Air Force global engagement responsibilities. The next step is for the Air Force to address issues such as defining the appropriate force mix and applicable missions, improving acquisition and research, and establishing a vision for ISR UAVs.

ISR UAV Force Mix and Missions

UAVs should be an integral part of an ISR enterprise consisting of manned, ground, UAV, and space assets. As discussed in Chapter 2, UAVs provide many unique contributions to the ISR mission, but UAVs have disadvantages which preclude them from ubiquitously replacing manned ISR assets. For example, automated sensor and information technology is not even remotely prepared to perform the battle management and command and control functions now handled by AWACS and JSTARS personnel. A

2000 Scientific Advisory Board study affirms this contention by stating that, " … UAVs are [not] inherently superior to manned systems. Because of the battle management and command and control (BMC^2) capabilities of the manned platforms, any direct comparison of the manned platforms to UAVs is truly an 'apples to oranges' comparison."[1] Thus, UAVs should be used in conjunction with existing platforms to perform functions such as long endurance surveillance where UAVs with advanced sensors can perform missions more efficiently than a manned or spaceborne counterpart.

Ultimately, the Air Force should employ UAVs as the workhorse of the ISR fleet. Figure 5 shows a concept of operations employing UAVs, manned aircraft, and satellites. In this scenario, UAVs are used to provide long endurance surveillance and are networked to the rest of the intelligence community through data links. The low-density, high-demand space and manned assets are reserved for contingencies where their unique skills are best utilized. This arrangement reduces the strain and operational tempo on high value assets while making optimum use of UAVs to extend ISR coverage.

UAVs are clearly primed for the ISR data collection mission; however, an effort to breakdown stovepipes between related disciplines will provide the opportunity for UAVs to perform other missions. Air Combat Command is investigating a reorganization of the current ISR architecture to include development of multi-mission, C^2ISR aircraft.[2,3] The new C^2ISR plane is projected as a common widebody (CWB) aircraft that will perform the functions of JSTARS, AWACS, Rivet Joint, and other ISR platforms. Moreover, the CWB will work cooperatively with UAVs to "extend the eyes and ears of the mother ship for both target location and deep look."[4]

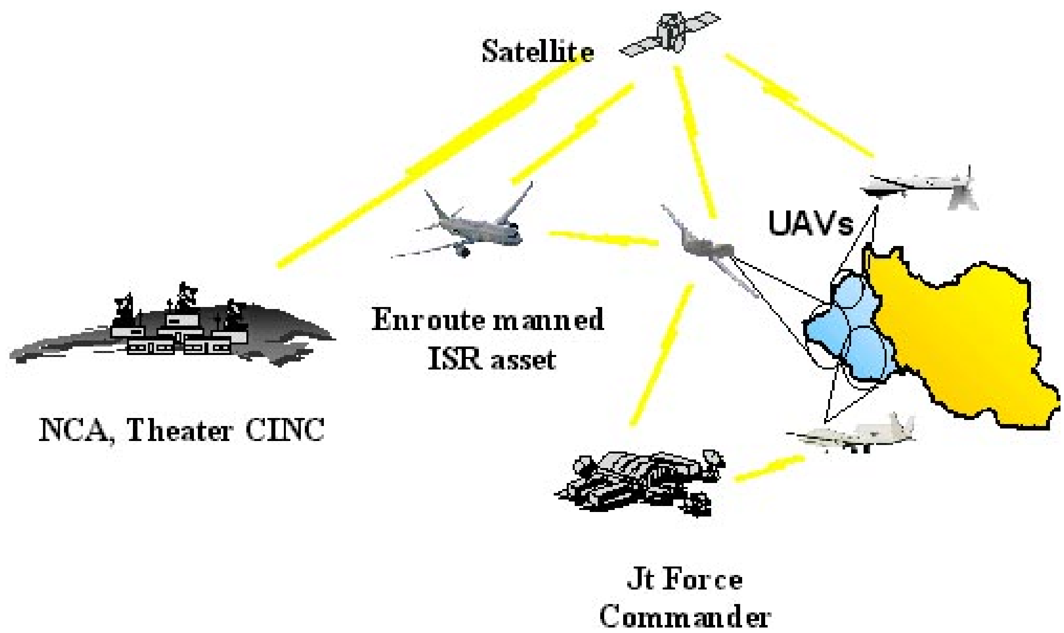

Figure 5. Notional concept of operations for combined use of UAVs and manned ISR assets.

UAVs provide long-term coverage and manned aircraft are saved for contingencies.

The Air Force should aggressively pursue multi-mission ISR assets as advances in technology facilitate the development of multi-mode sensors suitable for both manned and unmanned vehicles. Recent developments from the JSF program demonstrate the ability for cutting edge avionics to perform previously disparate missions. The JSF was initially expected to rely on off-board sources for situational awareness, but innovative use of AESA technology and the availability of advanced computational power has produced a revolutionary avionics suite that can simultaneously perform ISR, electronic warfare, electronic eavesdropping, information operations, and other tasks.[5] As stated by a senior JSF executive, " … the line between electronic warfare and radar, for example, is forever blurred, and I believe that in 20 years you will hardly be able to tell the difference."[6] Hence, the Air Force will gain tremendous leverage from UAVs which can concurrently support ISR and other missions such as IW, ESM, and communications.

UAV and Sensor Technology Base

The technology breakthroughs envisioned for future UAVs and sensors require a healthy commitment to research. The Air Force must provide sufficient and stable funding to support research and development (R&D). Several studies are sharply critical of the Air Force's handling of R&D in recent years. A 2000 report from the Air Force Association stated that over the last decade, "…the Air Force has gone from first to last among the armed services in the amount it spends on Science and Technology."[7] Moreover, the Air Force budget for R&D has fallen by more than 50% since 1989 and is still in decline.[8] The predicted impact of this shortfall in funding is that, "… the most promising technologies, such as directed energy, miniaturized munitions, new electronics countermeasures techniques, unmanned combat aerial vehicles, and improved materials for space power, may not be ready to be incorporated into Air Force systems to be fielded through 2020."[9] An industry review of overall DoD R&D funding also concluded, "…the group fails to understand why the basic enabling technology efforts fundamental to achieving affordable weapons systems (on both Acquisition and a Total Ownership Cost basis) continue to be reduced in disparate proportions."[10] Consequently, DoD and particularly the Air Force must act to provide sufficient funding to keep the pipeline of revolutionary air power technologies flowing.

In addition to providing sufficient money, the Air Force must also stabilize funding for R&D. Air Force R&D funding has fluctuated significantly over the past few years as the service struggles to balance readiness with modernization concerns.

However, the R&D budget has been rocked by severe changes such as absorbing the bill for the Discoverer II and Space-based Laser programs.[11] A negative impact of erratic funding is that research programs are annually cancelled or extended. These programmatic perturbations significantly increase cost and delay the arrival of new military capabilities. The Air Force must protect its precious investment in the future by stabilizing the funding of R&D programs such as the ones supporting ISR UAVs.

The R&D community can also mitigate funding issues through more efficient use of the funds that are received. Acquisition reform efforts have produced savings through streamlining extraneous regulations and specifications, and every effort must be made to decrease the acquisition time and contracting costs of new technology.[12,13] Cost-saving innovations such as simulation-based acquisition and spiral development are suitable for implementation in ISR UAV programs.[14] These reforms are considered key elements of the acquisition strategy that enabled the cost-effective and rapid development of the Predator and Global Hawk UAVs.[15,16] Furthermore, combining concurrent research and acquisition programs can produce significant savings. For example, insightful consolidation of discrete A-10 upgrades reduced overall costs from $450M to $300M while shortening the development time.[17] Smart acquisition techniques will reduce the cost of acquiring ISR UAVs; and affordability is essential to ensuring UAVs are cheap enough to justify their losses in combat.[18]

The Air Force should also avoid the mindset that all R&D programs must produce quantifiable, near-term results. There is a natural tendency to adopt a near-term, risk-adverse focus in times of scarce funding, but the Air Force must protect its “seed corn” investments in the future.[19] Desert Storm success stories such as AWACS, JSTARS, stealth, and the Global Positioning System (GPS) were the result of decades of development with financial and institutional advocacy from the Air Force. These successful innovations flourished because leaders understood some programs would fail or develop slowly. However, the payoff for pursing cutting edge research is the creation of revolutionary technology such as GPS, which has far exceeded expectations. Hence, the Air Force must "invest broadly in defense-relevant scientific fields because it is not possible to predict precisely in which areas the next breakthroughs will occur."[20]

A few examples of high-payoff research areas for ISR UAVs include new types of sensors such as low-frequency radar for foliage penetration, ground penetrating radar for finding buried targets, and ultrawide band radar for scanning through walls. In addition, MEMS, conformal antenna arrays, and micro air vehicles should be investigated to provide inexpensive, miniaturized platforms and sensors to conduct close-in ISR in situations where larger UAVs are not effective. Finally, the development of information technology and algorithms to support dynamic and/or bistatic operation of UAVs with manned and space aircraft is another high payoff research area which supports revolutionary new ISR capabilities for the Air Force.

A Vision for ISR UAVs

The Air Force should also consider adopting a vision for development and employment of UAVs for the ISR mission. Just as Joint Vision 2020 provides a template and strategic direction for military transformation, an ISR UAV vision would provide a common reference point to guide development and planning. The existence of a shared vision allows warfighters to inform the R&D community of their current and anticipated needs while also providing a conduit for researchers to paint a picture of future capabilities and technology. Another benefit of a vision is that it provides focus to R&D efforts without being overly restrictive. A long-term vision provides a reference scientists can use to get a "heading check" on the potential military application of their work. Thus, productive R&D can continue even when operational or funding considerations inhibit the fielding of new technology. A vision for ISR UAVs would allow the R&D community to nurture and expand the technology base while allowing flexibility to skip fielding of new systems until the Air Force is ready.

The Air Force Research Laboratory's Sensor Craft concept is an excellent starting point for a unifying ISR UAV vision. The Sensor Craft vision peers twenty years into the future to examine what the ISR UAV after Global Hawk should look like.[21] DoD and industry experts were consulted to assess future ISR needs of the warfighter and the national command authority, predicted advances in technology, and available funding. After this data was digested, a concept and vision for 'the ISR UAV after next' was constructed. The Sensor Craft vision incorporates a wide range of emerging technologies to allow full exploitation of the electromagnetic spectrum and provide long dwell, omni-directional ISR coverage (see Appendix A).[22]

Concurrent development of the airframe, sensors, and concept of operations is one of the central themes of the Sensor Craft vision.[23] This systems engineering approach enables engineers to optimize the design of all components to make the best UAV possible. The initial response from the DoD community to the Sensor Craft vision has been overwhelmingly positive. Furthermore, several organizations in the warfighting, acquisition, and R&D communities are now collaborating to mold Sensor Craft into a unifying vision for ISR UAVs.[24]

The development and adoption of a unifying vision such as Sensor Craft will greatly assist the Air Force in the development of ISR UAVs and sensor technology. A vision will help the Air Force overcome the malady identified by Sir Winston Churchill:

> "A hiatus exists between inventors who know what they could invent, if they only knew what was wanted, and the soldiers who know, or ought to know, what they want, and would ask for it if they only knew how much science could do for them. You have never really bridged that gap yet."[25]

Furthermore, the Air Force has other major issues to address including development of doctrine for ISR UAV employment and resource prioritization. There are compelling reasons to field ISR UAVs, and the Air Force should continue to proactively acquire the capability to globally project air power.

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Chapter 5

Conclusions

Many intelligence reports in war are contradictory, even more are false, and most are uncertain.

—Carl von Clausewitz

The necessity of procuring good intelligence is apparent and need not be further urged.

General George Washington[1]

While there may be debate on the absolute truth of Clausewitz's assessment of intelligence, both his and General Washington's perspectives highlight the necessity for the Air Force to diligently pursue innovative ways of providing timely, accurate, and relevant intelligence reports to military commanders. This paper demonstrates that UAVs equipped with advanced sensors and information technology are one arrow in the quiver of intelligence tools available to the ISR community of the 21st century. In particular, there is a strong and growing need for increased ISR capability, and advances in technology have set the stage for aggressive pursuit of UAVs for the ISR mission. Air power advocates must not neglect the enormous potential of airborne ISR to uniquely influence military operations, and UAVs with advanced sensors represent a prominent aspect of future airborne ISR.

Implications of Research

As stated in Chapter 1, this research effort was launched to address the questions of (1) should the Air Force proceed with aggressive development of UAVs for ISR, and (2) what are key considerations to improving the return on investment in UAV and ISR sensor technologies. In answering the first question, Chapter 2 illustrated the growing importance of ISR as the Air Force undergoes the transformation from a Cold War conventional force towards an expeditionary force with worldwide operations. Moreover, Chapter 2 documented that UAVs have been superb ISR performers in Air Force operations in the 1990's and possess the potential to provide a cost-effective means of enhancing the nation's ISR capability. Clearly, the US should continue to pursue UAVs for ISR missions to maintain and extend its air power advantage.

Chapters 3 and 4 addressed the second research question of improving the development of UAVs and sensor technologies. These chapters show that the Air Force must embrace emerging sensor and information technology and make wise decisions to maintain the pace of innovation. Technological advances are rapidly redefining old paradigms on how to best conduct the ISR mission. In the near term, the Air Force should continue efforts to integrate UAVs with other manned and spaceborne ISR assets. The horizontal integration of these assets into a tightly coupled system of systems will provide a great leap forward. For the long-term, the Air Force must address its shortfalls in R&D funding. A healthy technology base is vital for revolutionary technologies such as MEMS, micro air vehicles, and hyper-spectral imaging. Finally, the Air Force should establish a unifying vision, such as Sensor Craft, for ISR UAVs to improve the dialog between warfighters and scientists as well as provide an aimpoint to focus planning and development.

Recommendations for Future Study

Areas for further exploration include performing a detailed, quantitative analysis of the optimum ratio of ISR UAVs, manned, and space assets to include consideration of the new multi-mission, manned aircraft currently under investigation. Also, a detailed analysis of sensor trade studies will help determine the right mix of sensors to meet future demand for ISR.

Ultimately, the most important evaluation of the suitability and air power potential of UAVs is determined through operational use. UAVs and sensor technologies may revolutionize the means used to collect ISR data, but skillful leadership is required to integrate these technical marvels into the larger intelligence community. As stated in AFDD 2-5.2, "While ISR platforms have evolved, the mission remains the same—provide the fullest possible understanding of the adversary to the commander."[2]

Notes

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Appendix A

Appendix A. The Sensor Craft Vision: "Tomorrow's Eyes and Ears of the Warfighter"

by Floyd Paul Johnson, AFRL

The Air Force Research Laboratory is formulating a program that holds high promise in providing revolutionary Intelligence, Surveillance, and Reconnaissance (ISR) capabilities only dreamed of here-to-fore. This ingenious program blends a wide spectrum of emerging technologies to produce an unmanned air vehicle configured and optimized to conduct multiple advanced sensing modalities integrated into an airframe that sustains an enduring theater presence. Extremely long endurance combined with omni-directional sensing enables a "virtual presence" allowing vantage point flexibility/optimization necessary for continuous and detailed theater air and ground target detection, identification and track. It's this unique combination of advanced sensors and sustained presence that enables continuous and rapid reaction to the dynamic combat operational requirements confronting current and evolving military operations.

Figure 1: Sensor Craft Role in the ISR Enterprise

As Figure 1 depicts, the Sensor Craft is the Airbreather component of a fully integrated ISR Enterprise that cohesively integrates Space, Air and Ground components of the total ISR apparatus. The technological construct goes far beyond the mere concept of information merging (e.g., cross cueing) to a level of automated integration adapting the sensor management to extract needed phenomenology to identify extremely difficult Camouflaged, Concealed, and Deceived (CC&D) targets. This includes multistatic interoperability with space assets and data exfiltration from “up close and personal” ground sensors. Several aircraft and propulsion candidate design/configurations are under study to determine the best trade between long endurance, altitude, engine efficiency and power generation all driven by the advanced sensor payload and RF aperture requirements necessary for the new sensing capabilities resulting in continuous All-Weather, theater air and ground target acquisition, geo-positioning, and tracking through to and including time-critical targets employing heavy CC&D. According to members of the design team, one of the most innovative aspects of this program is the integration, into the structural components of the aircraft, the large antenna apertures required for lower frequency operations. It’s in these lower frequency bands of operation that the Sensor Craft will provide a foliage penetration radar capability; a key sensory mode aimed at negating an age old, and extensively practiced, CC&D capability.

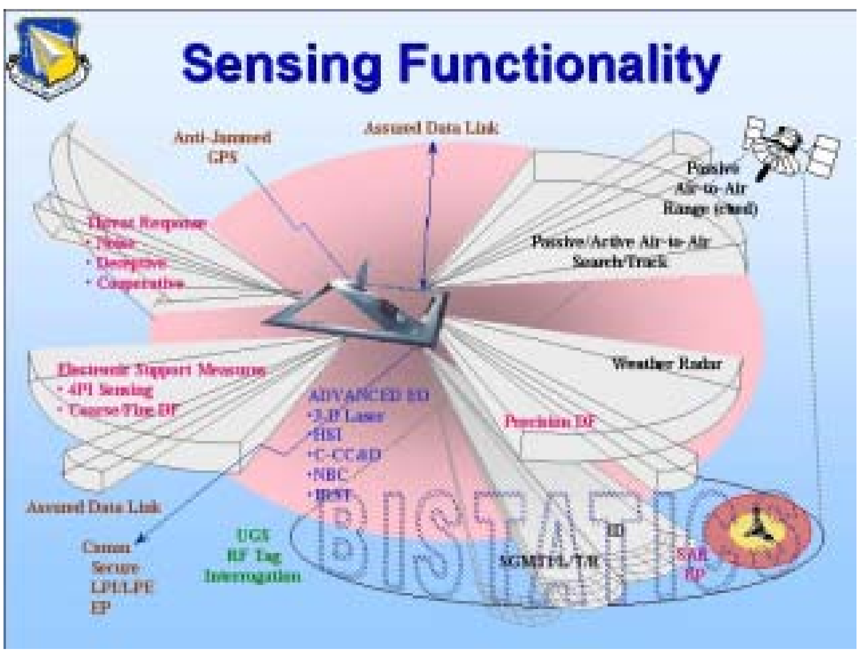

Figure 2: Sensor Craft’s Advanced Sensor Multi-modality and diverse functionality.

Figure 2 illustrates the advanced sensor functionalities and modes being designed into the Sensor Craft vehicle. Advanced RF capabilities include radar and Electronic Support Measures (ESM) fully integrated into the aircraft structure. ESM will likely be split into a High Band and Low Band of operation with radar functions to include Air Moving Target Indication (AMTI), Ground Moving Target Indication (GMTI), Synthetic Aperture Radar

(SAR), foliage penetration SAR with these functions operational in both monostatic and bistatic modes. Data exfiltration of the ground sensory component of the ISR infrastructure will be integrated into the RF system on-board the Sensor Craft. Non-lethal self-protection will be performed in a manner explicitly tailored to the threat including noise, deception and cooperative countermeasures. Emerging Electronic Protection (EP) techniques will be integrated into Sensor Craft for providing new levels of sophisticated hardening against more advanced Electronic Warfare (EW) technologies that may be potentially developed by the more advanced adversaries. Assured data links to within theater elements with Laser communication up/cross links for reach back to CONUS are already defined with long lead technical elements under development. The EO sensory suite includes Infrared Search and Track (IRST), as an adjunct to long range AMTI; Hyper Spectral Imaging (HSI), as an emerging technology enabling exploitation of phenomenologicly derived, yet subtle attributes associated with the CC&D and Chemical-Biological sensing/targeting problem; and 3-D Laser imaging, an advanced sensing capability with extremely high resolution and precise 3-D information critical for Intelligence Preparation of the Battlefield (IPB) and advance target recognition and positioning capabilities.

Figure 3: Featured Air Vehicles Technologies for Sensor Craft

Advanced Air Vehicle technologies, Figure 3, will feature new design approaches to enable the embedding of the radar antenna into the actual load bearing structure itself achieving a new level of electrical-structural integration. Advanced concepts in unitized metallic castings will reduce weight while substantially lowering the cost of manufacturing. Additionally, it's important to note that the aero efficiency of the wing design for high altitude, long endurance operation involves design and validation. We're confident that efficiency improvements in excess of 10% can be achieved through L/D Optimization. This is most significant when you consider that 10% L/D improvement on Global Hawk (as an example) will increase mission duration by four hours. The combined impact on these Air Vehicles Technologies is expected to lower the O&S costs while dramatically improving vehicle efficiency resulting in reducing the Gross Vehicle Take Off Weight between 25% - 50%. This vehicle weight reduction has a profound impact on lowering the acquisition cost of the platform.

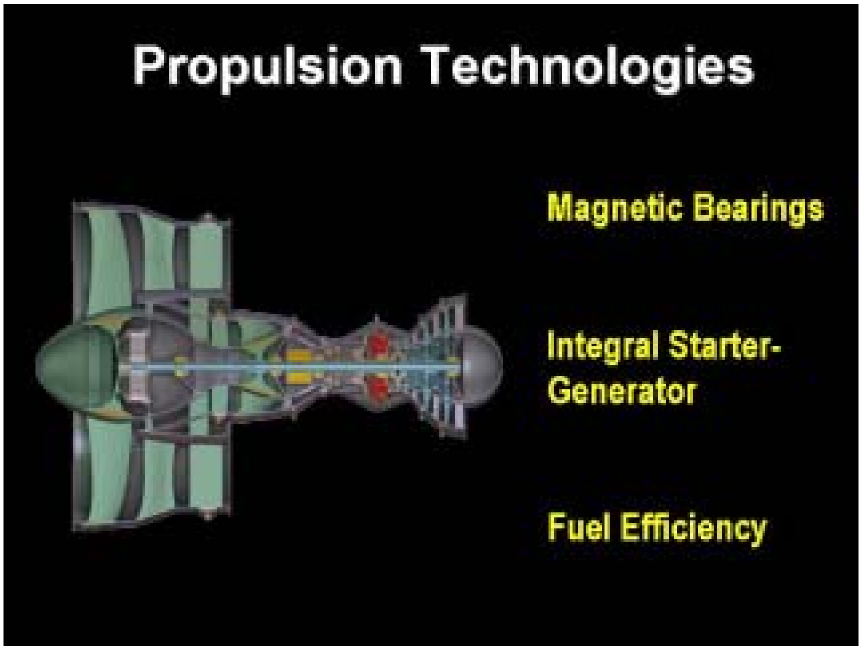

Figure 4: Advanced Propulsion Technologies

Dramatic improvements in engine reliability will be provided through Advanced Turbine Engine technologies featuring magnetic bearings and an integral starter-generator (see Figure 4). The advantage of the magnetic bearings is the elimination of the dependence on liquid oil for lubrication. This is an important factor and currently represents a major limitation of endurance on contemporary wide-body ISR platforms. Secondly, an integrated starter-generator reduces the parts and need for external gearing necessary in conventional engines. This results in weight reduction and substantial improvements in engine reliability. Lastly, technological improvements in engine materials and aerodynamic design are expected to improve engine performance and reduce specific fuel consumption by up to 35%. For a vehicle driven by endurance, this has an incredible impact on the vehicle. Specifically, for the objective 80 hour mission duration for Sensor Craft, this 35% fuel efficiency improvement reduces the Gross Vehicle Take Off Weight by 50%!

Figure 5: Product of the Integrated ISR Enterprise; Rapid, Precise Force on Target

In summary, the Sensor Craft concept represents a diverse, multi AFRL Directorate, shared vision to innovatively combine the emerging (and rather diverse) technologies associated with flight vehicles, propulsion, sensors, and information into a highly responsive thrust to provide revolutionary capabilities in ISR. These advanced sensor functionalities, integrated into an aircraft explicitly developed to enable an enduring theater persistence, will constitute the airborne component of the "Integrated ISR Enterprise". Truly, the role of Sensor Craft, and it's functionality within the ISR Enterprise, represent an innovation in providing the Warfighter the "Eyes and Ears" to flexibly respond to Dynamic Combat Operations with the right "Force on Target" (Figure 5).

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Glossary

ACSC	Air Command and Staff College
ACTD	Advanced Concept Technology Demonstration
AESA	Active Electronically Scanned Antenna
AWACS	Airborne Warning and Control System
BDA	Battle Damage Assessment
BMC^2	Battle Management, Command and Control
C^2	Command and Control
CWB	Common Wide Body
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
EO	Electro-Optical
ESM	Electronic Support Measures
EW	Electronic Warfare
GPS	Global Positioning System
HSI	Hyperspectral Imaging
IR	Infrared
ISR	Intelligence, Surveillance, and Reconnaissance
IW	Information Warfare
JSF	Joint Strike Fighter
JSTARS	Joint Surveillance Targeting Attack Radar System
MAV	Micro Air Vehicle
MEMS	Micro Electro Mechanical Systems
NMS	National Military Strategy
RTIP	Radar Technology Insertion Program
RF	Radio Frequency
R&D	Research and Development
SAB	Scientific Advisory Board
SAR	Synthetic Aperture Radar
T/R	Transmit/Receive
UAV	Unmanned (or Uninhabited) Aerial Vehicle
UHF	Ultra High Frequency
USAF	United States Air Force
VHF	Very High Frequency

Definitions

Active electronically scanned antenna (AESA). AESAs combine the output from an array of small, individual transmit-receive (T/R) modules to create a composite antenna pattern. An AESA antenna pattern is electronically scanned by controlling the output of each T/R module. An AESA can move its antenna beam much more rapidly than a mechanically scanned antenna and has higher reliability due to the reduction in moving parts.

Hyperspectral imaging (HSI). A hyper-spectral system examines hundreds of frequency slices in the electromagnetic spectrum for patterns or anomalies. Most materials have unique spectral features, and HSI measures the absorption pattern to find target characteristics not visible by other sensors.

Intelligence. Information and knowledge about an adversary obtained through observation, investigation, analysis, or understanding. (Joint Pub 1-02)

Micro air vehicle (MAV). A MAV is a fully functional air vehicle with dimensions of less than 6 inches in length, width, and height.

Micro-electro-mechanical systems (MEMS). MEMS is a collection of processes used to fabricate mechanical devices with micron (10^{-6} meters) feature sizes by using many of the techniques used in the semiconductor industry. MEMS devices are already prevalent in the automotive industry (air bag deployment and pressure sensors), ink printers (nozzles), and optical projectors.

Reconnaissance. A mission performed to obtain information about an enemy or to secure data concerning the physical characteristics of an area. (Joint Pub 1-02)

Sensor. Device which detects, indicates, and/or records objects and activities by means of energy or particles emitted, reflected, or modified by objects. (Joint Pub 1-02)

Surveillance. The systematic observation of aerospace, surface or sub-surface areas, places, persons, or things, by visual, aural, electronic, photographic or other means. (Joint Pub 1-02)

Unmanned aerial vehicle. A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload. (Joint Pub 1-02)

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